Conceptual Surface Power Cases for Mars

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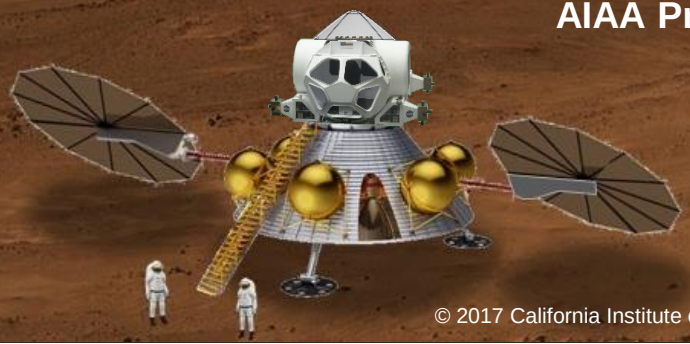
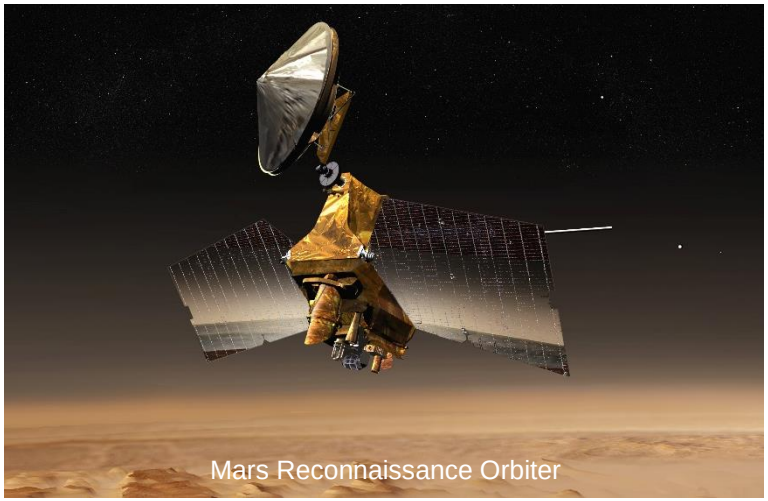
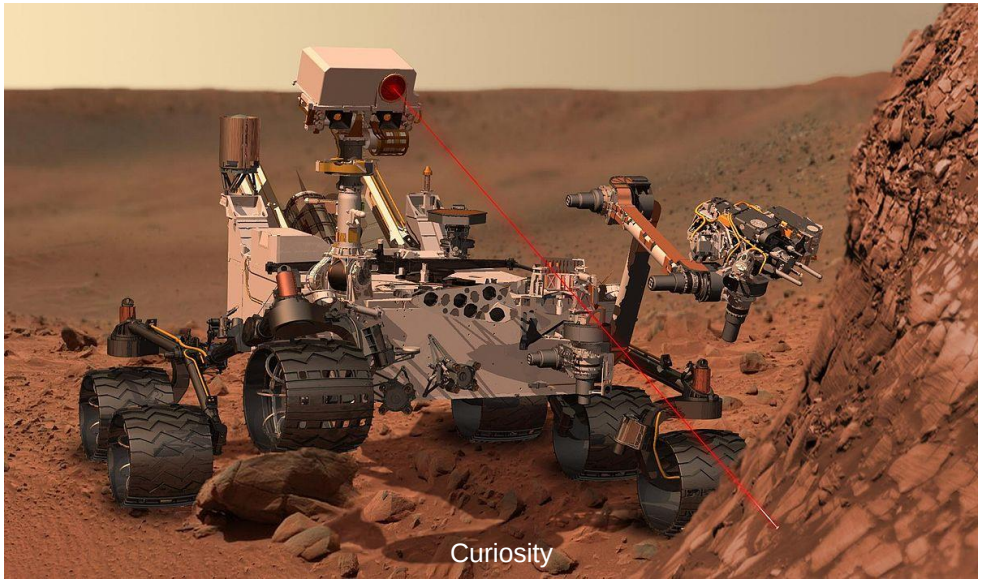


Current Vehicles at Mars

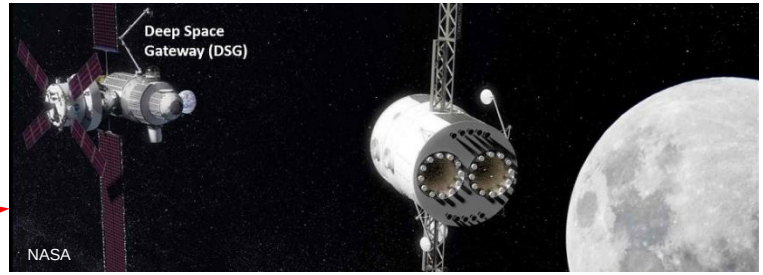
- Orbiters
  - MAVEN, MRO, Odyssey
  - Trace Gas Orbiter, Mars Express
  - Mangalyaan (India)
- Rovers
  - Curiosity (MSL), Opportunity (MER)
- More on the way:
  - Mars 2020 rover
  - ExoMars rover (ESA)
  - Hope orbiter (UAE)
  - Chinese orbiter
  - Chinese lander and rover
  - Mangalyaan 2 (India)
  - Red Dragon(s)? (SpaceX)

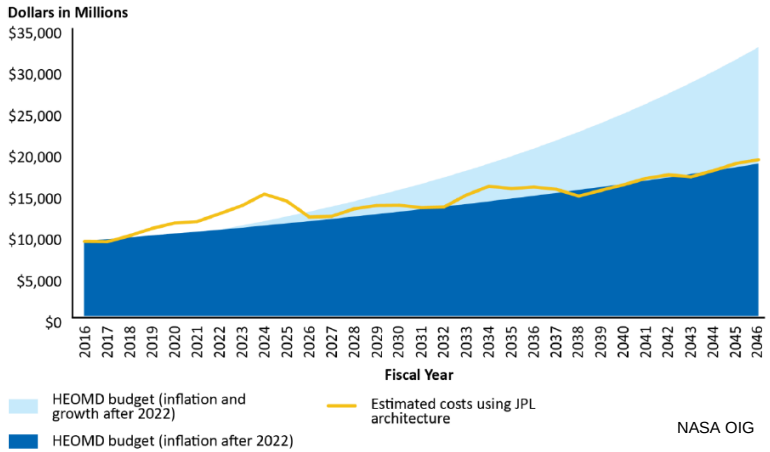

Mars Reconnaissance Orbiter


Curiosity

Concepts for Affordable Human Missions to Mars

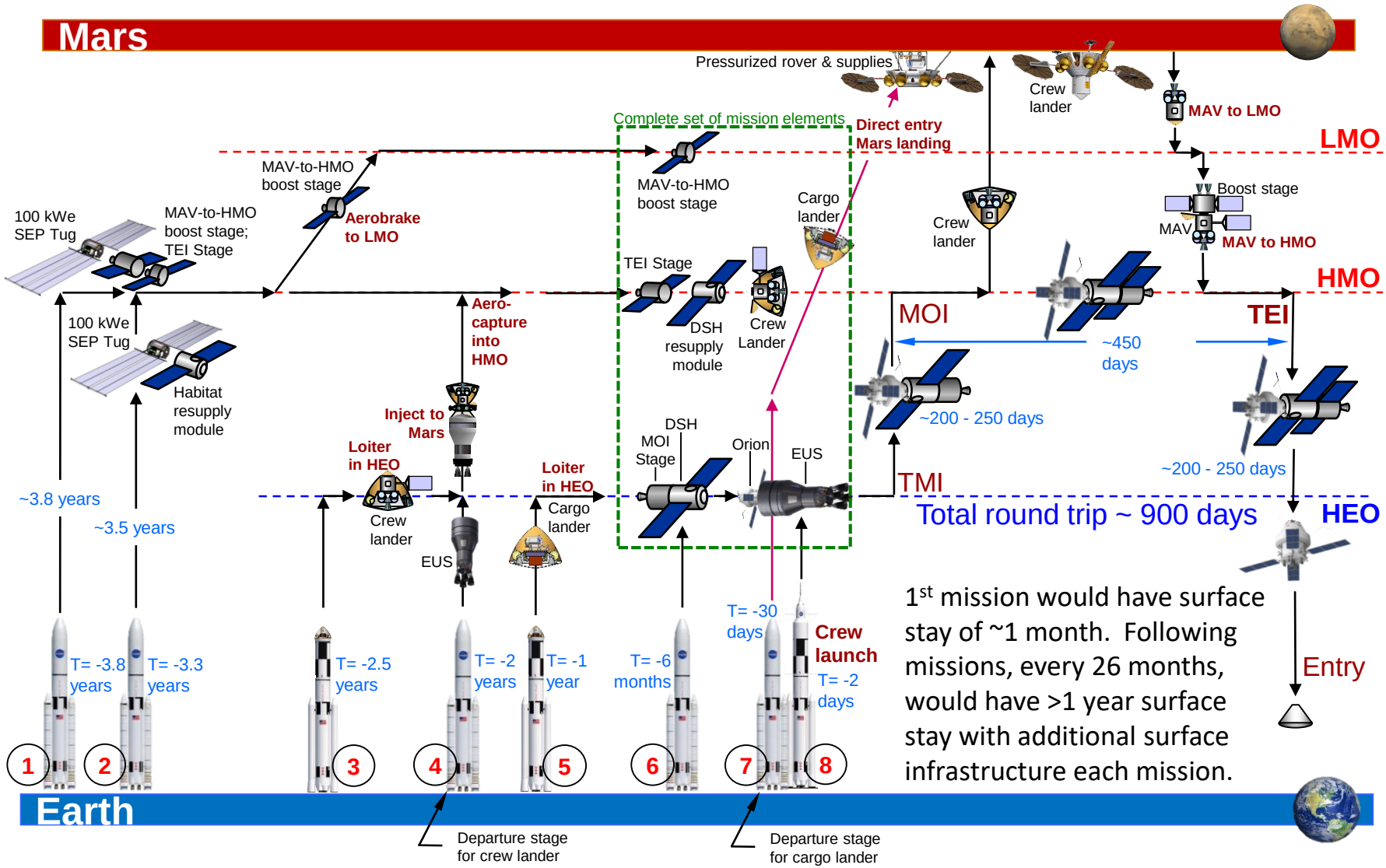
- There are a number of viable architectures for human exploration of Mars:
  - NASA SEP/chemical hybrid option
    - Deep Space Transport concept that operates from a Deep Space Gateway
  - Lockheed Martin "Basecamp" and lander
  - Boeing (similar to NASA architecture)
  - SpaceX reusable Mars architecture
  - JPL Minimal Mars architecture
  - Many others
- JPL Minimal Mars has been costed by the Aerospace Corporation and audited by the NASA Office of the Inspector General
  - Example of an architecture that could, to a first order, fit within NASA's budget adjusted for inflation
    - Costs could be reduced by international contributions and by descoping the first Mars orbital mission (e.g. no Phobos)





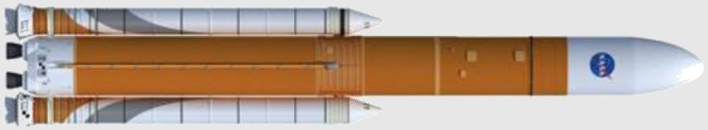
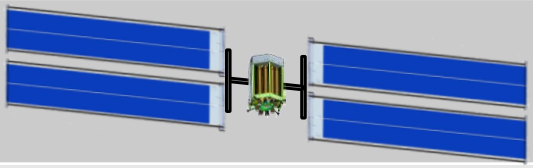
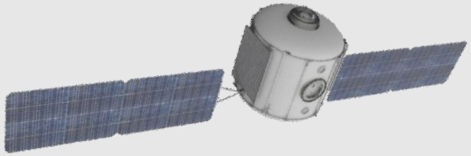
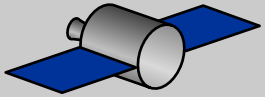
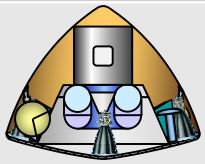
Minimal Architecture Concept

Crew of 4 to surface; 8 SLS launches

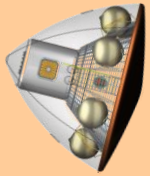


1st mission would have surface stay of ~1 month. Following missions, every 26 months, would have >1 year surface stay with additional surface infrastructure each mission.

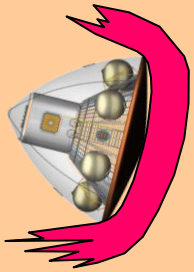
Six Vehicle Types That Could Enable Crewed Missions to Mars

Vehicles	# Vehicles per Mission
Orion 	1
SLS 	8
SEP Tug ~100 kWe 	2
Deep Space Habitat (One is a resupply version) 	2
In-Space Chemical Propulsion Stage 	3
Mars Lander (One crew and one cargo) 	2

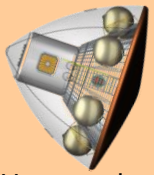
EDL Concept for Crewed Mars Lander



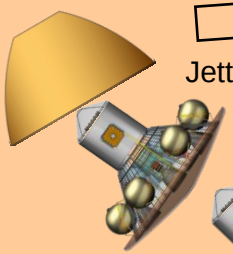
Entry



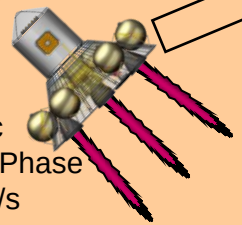
Peak Heating



Hypersonic
Aeromaneuvering
Mach 5
Alt: 4.2 km



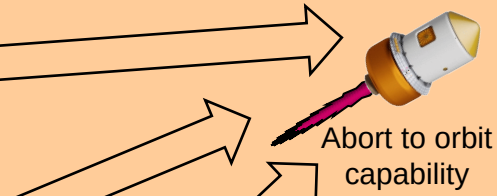
Jettison Backshell
Mach 3.65
Alt:3.2 km



Supersonic
RetroProp Phase
Vel: 828 m/s
Alt: 3 km

Heatshield jettison
Vel: 414 m/s
Alt: 1.29 km

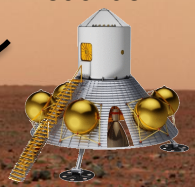
Powered Descent
Const. Vel. Phase
Altitude: 40 m



Abort to orbit
capability

Ground Acquisition

Touchdown



Note: There are no deployable decelerators or parachutes.

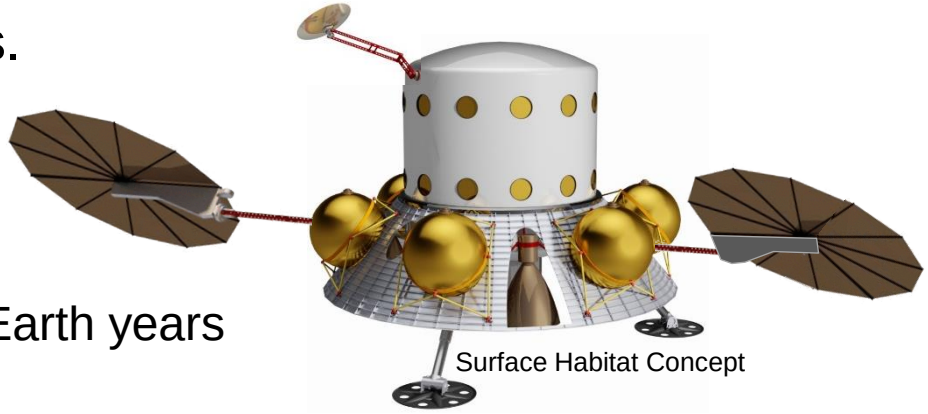
The Range of Planetary Surface Environments

- Mars equatorial – proven solar survivability (MER)
- Mars 40° latitude
  - Large accessible ice deposits near surface
  - Challenging, but might be possible with solar power
- Mars polar
  - Access to ice
  - Would require nuclear power for long missions
- Caves (Mars or Moon) – total darkness
- Lunar non-polar – 14 days of darkness
- Lunar Shackleton Crater
  - Rim: ~1.5 days of darkness
  - Inside: total darkness

Human Mars Surface System Conceptual Power Cases

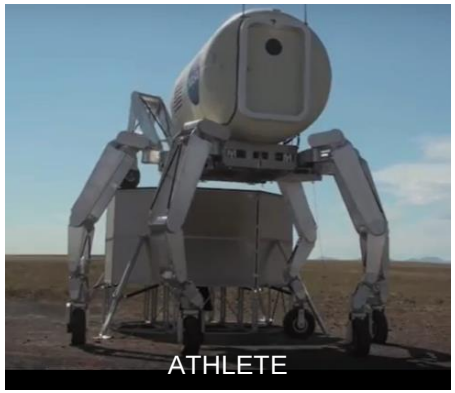
- ISRU vs. non-ISRU
  - Significant difference in power (ISRU ~20 kWe)
- Surface habitat power (~15 kWe)
- Pressurized rover power options (~5 kWe)
  - Solar and batteries
  - Fuel cells
  - 5 kWe class advanced Stirling RTGs
- Central vs. distributed power vs. flexible hybrid architecture
- Dust storm survival
  - Infrequent, but can be severe
  - Opportunity has survived >13 Earth years

Pressurized Rover

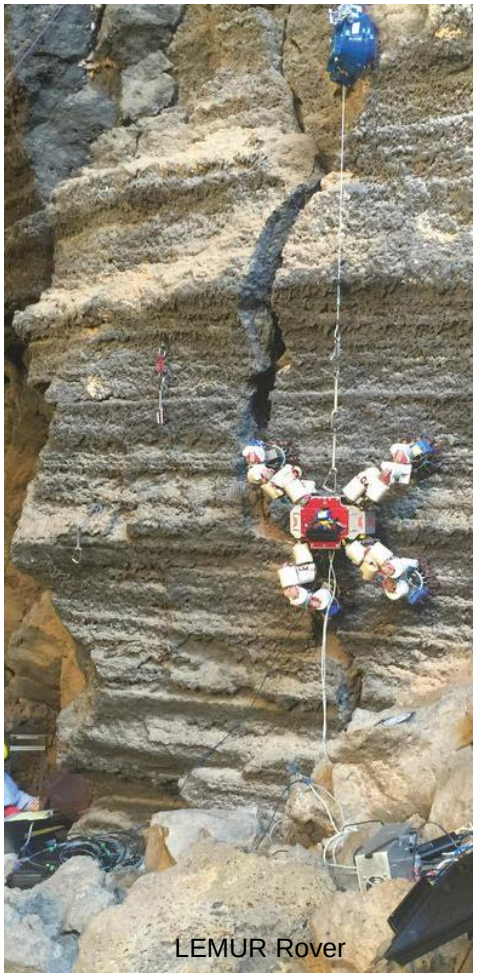

Surface Habitat Concept

Robotic Vehicle Concepts to Support Human Missions

- ATHLETE type vehicles to relocate large elements
- Tractor type vehicles for digging and moving regolith
- Moderate to deep drilling systems
- Fine manipulator rovers to configure crew transfer tunnels, ISRU connections, troubleshooting and contingency deployment of arrays and radiators, perform inspections and repairs
- Telecom relay rovers
- Teleoperated sterilized rovers for special regions
- Extreme terrain exploration rovers (cliffs, caves)


ATHLETE


DuAxel Rover


LEMUR Rover